

MECHANICAL DESIGN & ANALYSIS OF A 200 MHZ, BOLT-TOGETHER RFQ FOR THE ACCELERATOR DRIVEN NEUTRON SOURCE*

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Abstract

A high-yield neutron source to screen sea-land cargo containers for shielded Special Nuclear Materials (SNM) has been designed at LBNL [1,2]. The Accelerator-Driven Neutron Source (ADNS) uses the $D(d,n)^3\text{He}$ reaction to create a forward directed neutron beam. Key components are a high-current radio-frequency quadrupole (RFQ) accelerator and a high-power target capable of producing a neutron flux of $>10^7 \text{ n/(cm}^2\cdot\text{s)}$ at a distance of 2.5 m. The mechanical design and analysis of the four-module, bolt-together RFQ will be presented here. Operating at 200 MHz, the 5.1 m long RFQ will accelerate a 40 mA deuteron beam to 6 MeV. At a 5% duty factor, the time-average d^+ beam current on target is 1.5 mA. Each of the 1.27 m long RFQ modules will consist of four solid OFHC copper vanes. A specially designed 3-D O-ring will provide vacuum sealing between both the vanes and the modules. RF connections are made with canted coil spring contacts. A series of 60 water-cooled pi-mode rods provides quadrupole mode stabilization. A set of 80 evenly spaced fixed slug tuners is used for final frequency adjustment and local field perturbation correction.

INTRODUCTION

The ADNS RFQ design incorporates technology validated by recent RFQ's developed at LBNL, including for the SNS Front End [3]. The use of proven and reliable fabrication and assembly methods permits construction using readily available machinery with fewer steps. The demountable structure also facilitates maintenance and repair. The design is well suited for high quantity production since it makes use of readily available materials using common fabrication processes.

DESIGN FEATURES AND CAD MODEL

The ADNS RFQ is a four vane cavity structure consisting of individual, demountable vanes. A detailed 3-D CAD model of the final design was developed. and is used here to present a description of the RFQ's design characteristics. An overall view of the 4-module RFQ is shown in Figure 1. Each of the four modules consists of four separate, solid copper, modulated vanes bolted together. Vane modulations are to be fly-cut using an NC horizontal mill. Fiducial surfaces that also act as mating surfaces will be machined directly onto the vanes to provide high precision during both machining and assembly. A single RFQ module is shown in Figure 2.

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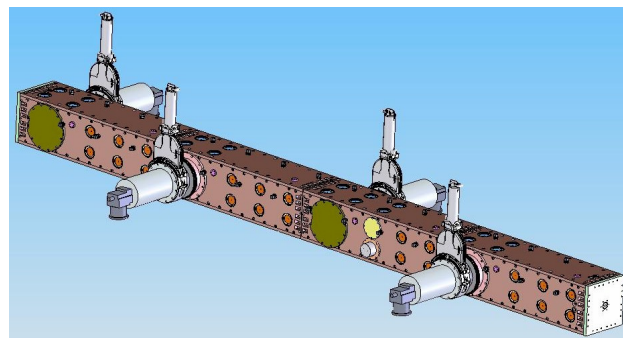


Figure 1: CAD model of assembled 4-module RFQ.

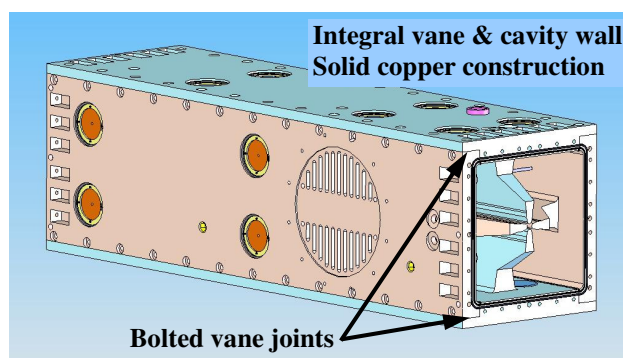


Figure 2: Single RFQ module.

RFQ VANE COOLING

Cooling passages are to be gun drilled through the vanes with plug welds at the end penetrations. At the beginning of Module 1 and the end of Module 4 there will be cutbacks in the vanes for proper termination of the RF cavity. Dedicated cooling passages will be incorporated in order to accommodate the added heat loads at the ends. A view of the vane cooling passages is shown in Figure 3.

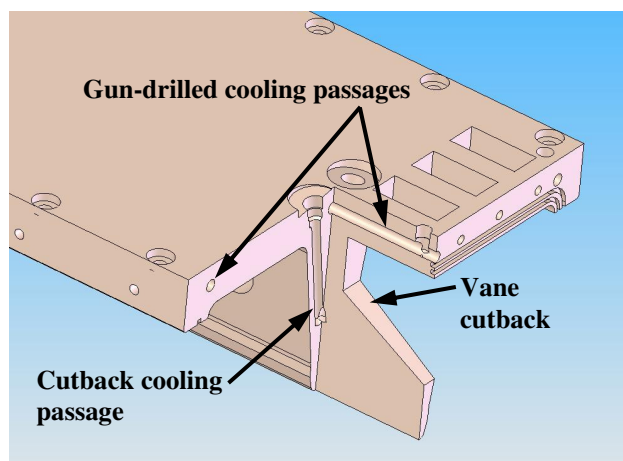


Figure 3: RFQ cooling passage details.

VACUUM SEALING AND RF JOINTS

Sealing between the vanes, between adjacent modules and at cavity wall penetrations will be achieved with O-rings for vacuum and canted coil springs for RF. This arrangement is shown in Figure 4.

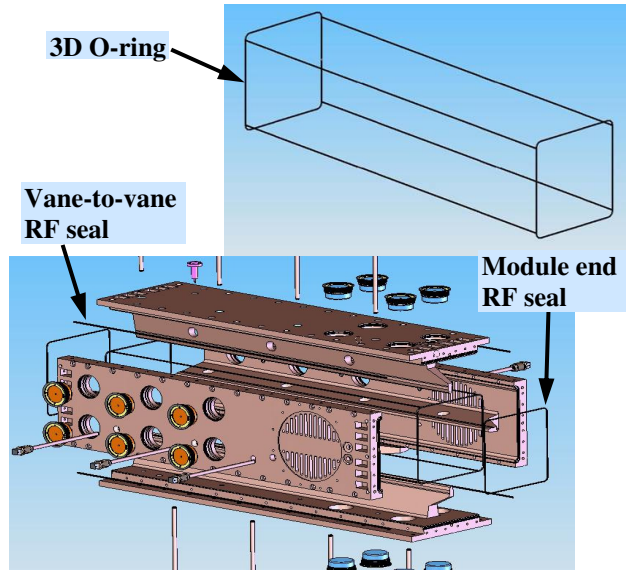


Figure 4: Details of the vacuum O-ring & RF spring seals.

A custom made, 3-dimensional O-ring that was developed for a previous LBNL designed RFQ will be incorporated. The O-ring contains axially running sections to seal between the vanes. The axial seals are joined to the module end seals using specially molded 'tee' sections. This design will provide a continuous vacuum seal between vanes and at the module ends for the bolt together construction. Canted coil springs will run axially at the cavity surfaces along the bolted joints between the vanes. The module-to-module RF joint will consist of a slightly raised, 3 mm wide copper lip around the periphery of the cavity that is backed by a canted coil spring to prevent any RF power from reaching the O-ring seal (see Figure 5). The proposed module end joint design was used successfully on the SNS RFQ.

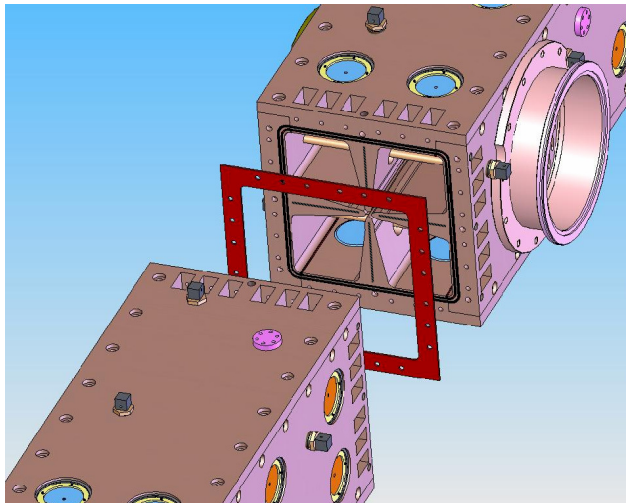


Figure 5: Details of the RFQ module end connections.

At the joints between adjacent RFQ modules, a thin copper plate (0.25 mm thick) is to be used to provide a flat surface for the facing O-ring seals and the canted coil RF springs to bear against. The copper plate has the same outside dimensions as the modules and a center cutout to match the inside of the cavity, without the vanes. The resulting 0.25 mm gap between the vanes will be accommodated with RF springs at the ends of the vanes.

RFQ VANE GEOMETRY

Two vane geometries will be used (major and minor) with the opposing vanes being identical. The penetrations and other features on the external vane surfaces are to be machined prior to finish machining of the cavity surfaces and the vane tips. This step in the fabrication process includes generation of tuner ports, RF coupling ports, cut back cooling passages, cooling taps, vacuum pumping ports, pi-mode rod penetrations, sensing loop ports, bolt pockets for module interconnection and through and threaded holes for vane-to-vane bolted joints. The modules are to be connected together using a 'flangeless' joint design in which the connecting bolts are recessed into the outer surfaces of the vanes. This technique, used successfully on the SNS RFQ, requires that the vane material remain in the hard (not annealed) state. In order to eliminate copper softening issues and to simplify the manufacturing process, the RFQ design does not use any metal brazing during fabrication. The exterior vane features are shown in Figure 6.

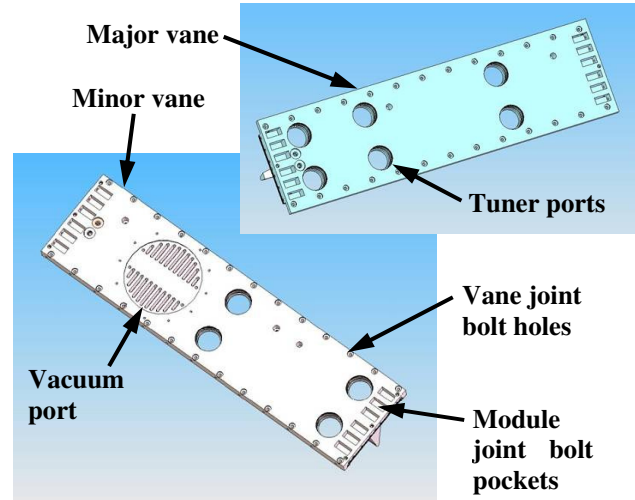


Figure 6: Major and minor vane external surface features.

PI-MODE STABILIZER RODS

A series of Pi-mode stabilizer rods (7 pairs in Modules 1 and 4 and 8 pairs in Modules 2 and 3) will be incorporated to provide RF mode stabilization (to minimize the dipole mode and maximize the quadrupole mode). The rods pass through the vanes and provide a direct connection between opposing cavity walls. The rods will be electrically connected to the cavity walls at each end using a canted coil spring RF joint. The rods will penetrate the cavity walls at one end only with an O-

ring providing the vacuum sealing. The opposite end of the rod will contain an RF spring ring and will be inserted into a blind hole in the cavity wall. The rods are 12.7 mm diameter hollow copper tubes incorporating a squirt tube for cooling that are to be machined from a solid copper cylinder such that all water joints are located outside of the cavity vacuum. Details of the pi-mode rod design and configuration are provided in Figure 7.

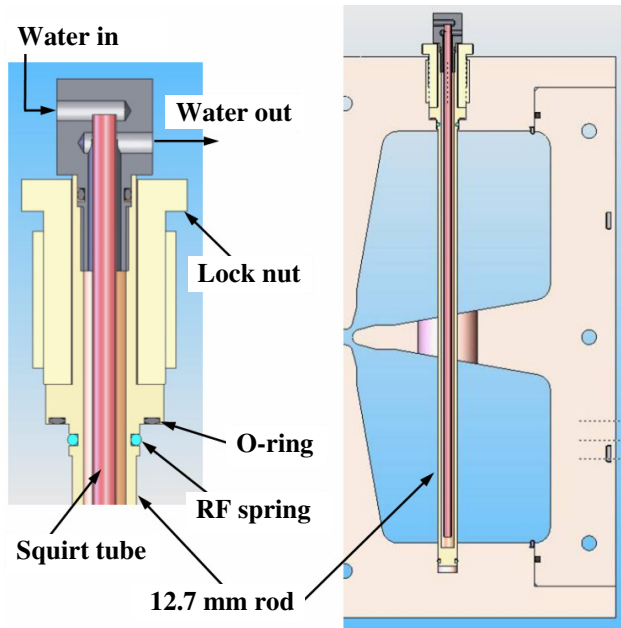


Figure 7: Pi-mode stabilizing rod design details.

CAVITY TUNING

Tuning of the cavity will be achieved by means of fixed slug type tuners distributed along the length of the modules similar to those used on the SNS RFQ. The final design uses 20 tuners per RFQ module (1 per quadrant at 5 evenly distributed locations). The tuners, shown in Figure 8, are to be machined from solid slugs of copper.

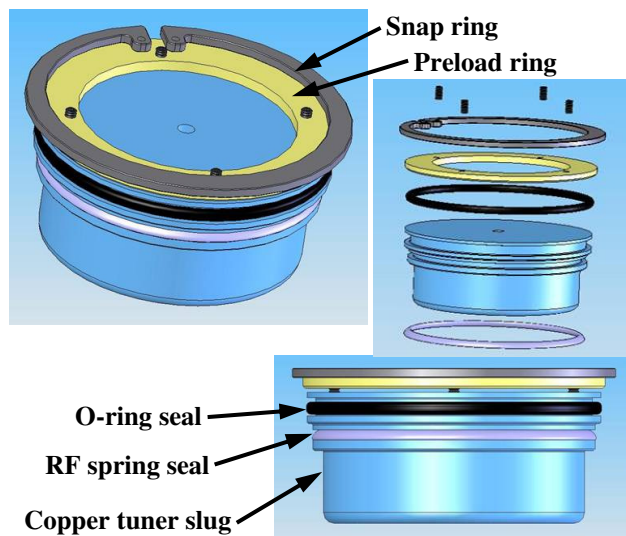


Figure 8: Fixed slug tuner design details.

Based on field measurements of the assembled RFQ (using a bead pull technique), each set of four tuners at a given axial location will be custom machined to predetermined lengths. Primary RF sealing will be accomplished by a step in the tuner OD that interfaces with the RFQ wall. Behind the step, an RF coil spring mounted on the tuner OD will protect the O-ring, also located on the tuner OD. Load plates using set screws will be held in place by a snap rings recessed in the cavity wall and will provide the necessary preload on the tuners.

MANUFACTURE AND ASSEMBLY

The ADNS RFQ preliminary design has been developed to ensure suitability for high quantity production. All aspects of the design incorporate both readily available materials and common, reliable fabrication processes that lend themselves to outsourcing through abundantly available shops. Each of the four vanes in a module are to be machined from a single piece of copper and will include simple cooling channels produced using an established gun boring technique. No brazing is required at any point in the construction process, thus avoiding potential braze failures and preventing material softening issues. The RFQ vane tips are to be modulated using a previously developed fly cutter technique on a commonly available programmable mill with easily achievable tolerances. Possible approaches to high quantity production of the rough copper vane blanks have been evaluated, including extrusion, casting, forging and billet machining. Based on the current price of copper and the available production techniques, direct casting of the rough "T" shaped vane sections appears to be the most cost-effective approach.

No special alignment fixtures or procedures will be required to connect the four RFQ modules together since the ends are designed to be self-aligning by means of dowel pins in the face of the ends. The bolted end connections are sufficiently strong and stiff such that the fully assembled 4-module RFQ can be lifted and handled as a single unit. This characteristic also allows the RFQ body to be supported using a simple kinematic (or 6-strut) system that will not impart any direct bending stresses on the assembled RFQ.

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